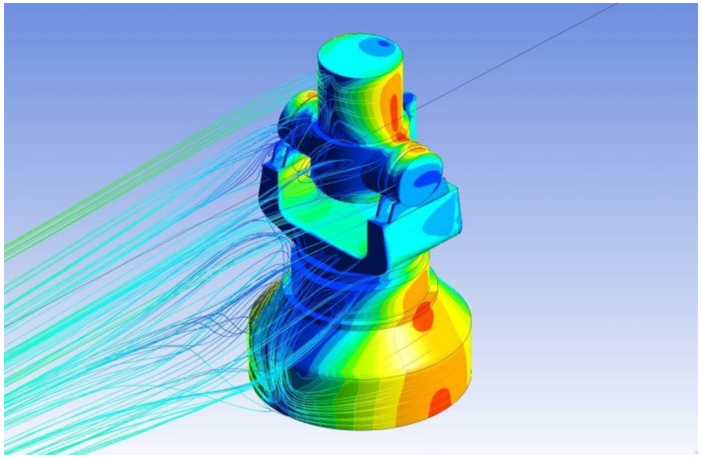
19th International Workshop on Laser Ranging 2014
Annapolis, USA

THE NEW GENERATION SLR STATION FOR TIME TRANSFER WITH THE SUBNANOSECOND ACCURACY AND LASER RANGING WITH THE SUBMILLIMETER ACCURACY IN THE DAYTIME AND AT NIGHT



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Agenda

1. Function, structure and technical characteristics of the new generation SLR station;

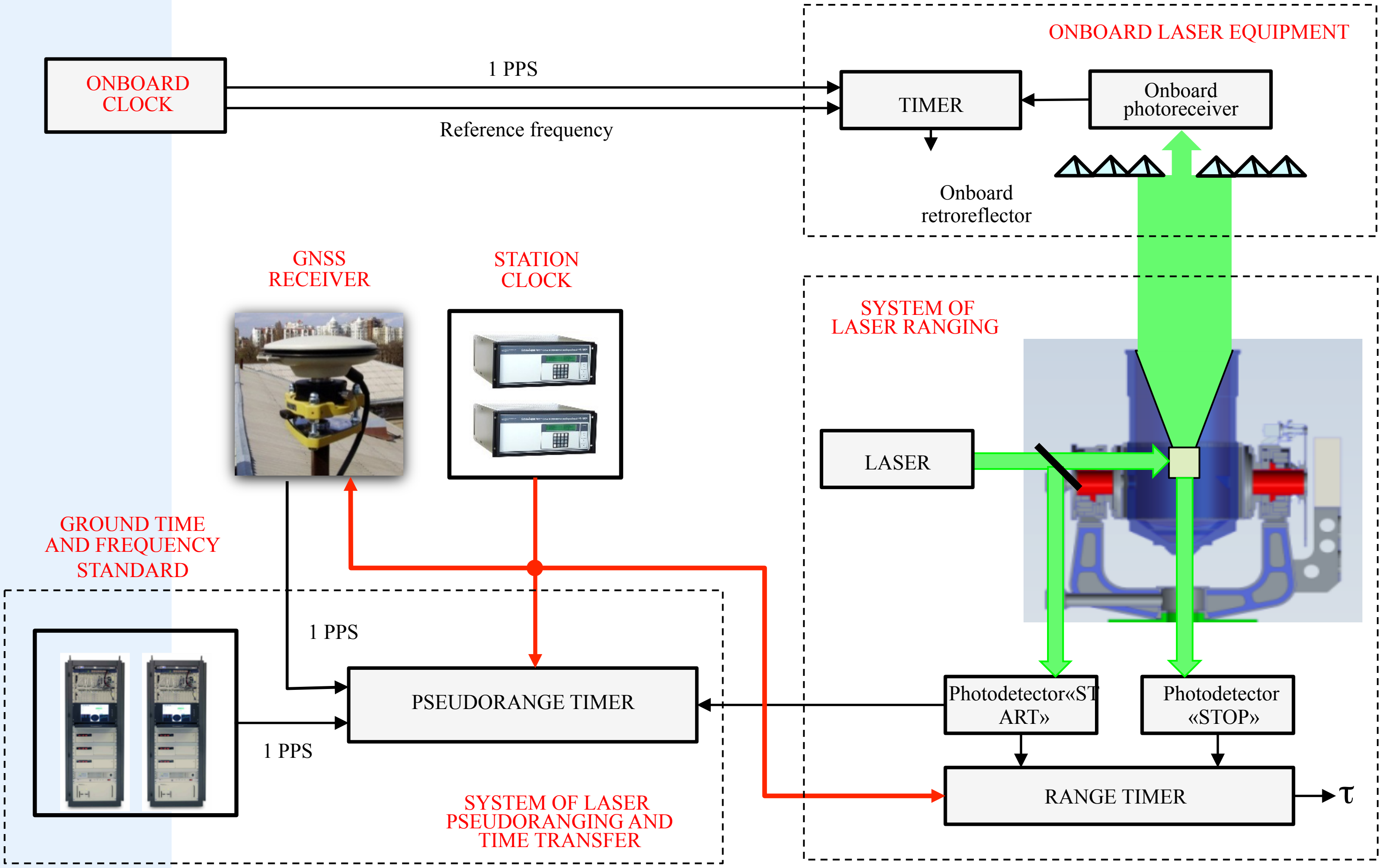
2. Problems of achieving the submillimeter accuracy of measurements in the daytime and at night;

3. Differential method for both laser ranging and normal point formation applied to the station in order to achieve submillimeter accuracy of measurements;

4. Methods of correcting the systematic bias of measurements, caused by:
   - influence of intensity of return laser impulses;
   - diffusion effects in single-electron photodetectors;
   - influence of the background of the scattered solar radiation;

5. Summary.

New generation SLR station

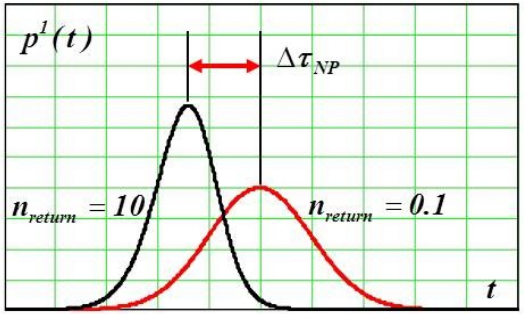


Technical characteristics of the new generation SLR station

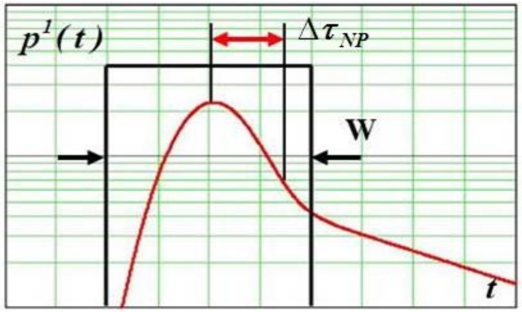
Parameter		Value
Receiving telescope main mirror diameter		***360 mm***
Telescope mount		***AZ-EL***
Transmitting telescope-refractor diameter		***50 mm***
Type of the star calibration camera		***CMOS***
Sensitivity of the star calibration camera	***night***	***14^m***
	day	***4^m-6^m***
Daylight optical filter bandwidth		***0.2 nm***
Laser transmitter wavelength		***532 nm***
Laser pulse energy		***2.5 mJ***
Laser pulse width		***< 50 ps***
Laser pulse repetition rate		***1000 Hz***
Laser beam divergence ($1/e^2$)		***12" – 48"***
Photodetector type		***Hybrid***
Range measurement uncertainty (NP on the interval of 30 s)		***< 1 mm***
Pseudorange measurement uncertainty in its own and external time scale		***< 50 ps***
Radio frequency pseudorange measurement uncertainty:		
	code phase	***< 0.1 m***
	carrier phase	***< 0.001 m***

Problems of achieving the submillimeter accuracy of range measurement

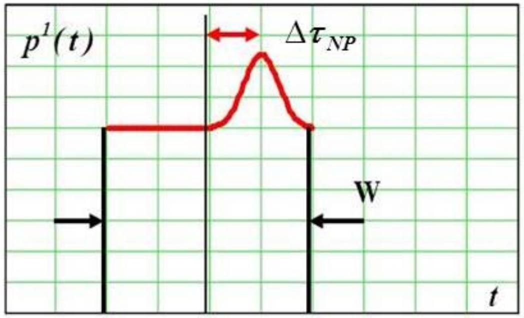
Systematic bias at normal points formation



First photon bias: bias of the return impulse arrival times distribution when the average number of photoelectrons in an impulse is increased. The offset value of the centroid bias can reach 20-80 ps



Diffusion bias: bias of the centroid to the distribution peak up on the presence of the diffusion tail in the photodetector response and measurements screening by the criteria of ±nσ. The offset value of the centroid can exceed 100 ps



Background bias: bias of the centroid of the return photoelectron arrival times distribution to the centroid of the joint distribution of return and background photoelectrons

Differential method of laser ranging and normal points formation

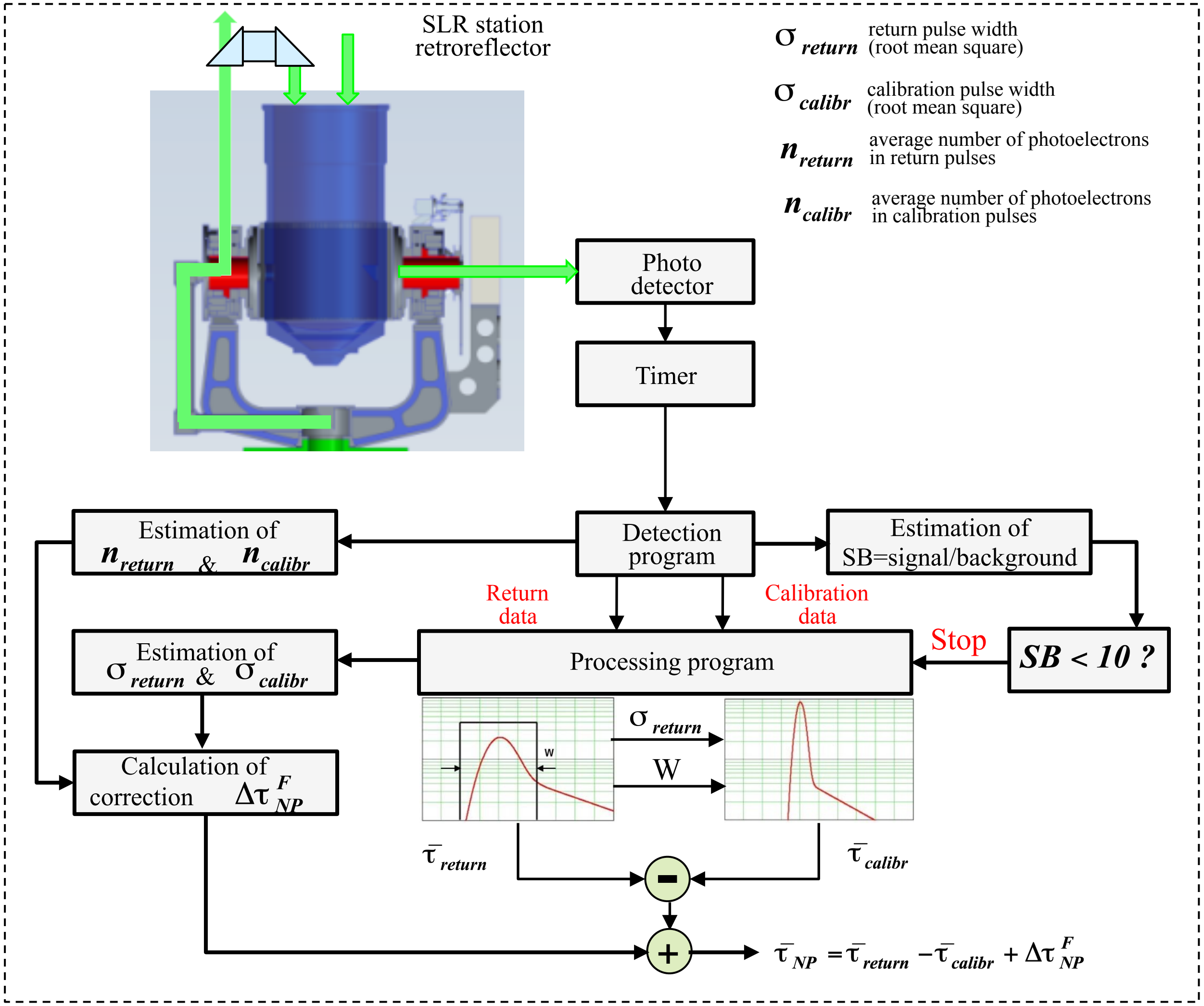
First photon bias
normal point correction

$$\Delta\tau^{F}_{NP} = \frac{1}{2\cdot\sqrt{\pi}}\cdot\left(n_{return}\cdot\sigma_{return} - n_{calibr}\cdot\sigma_{calibr}\right)$$

Background bias
normal point correction

$$\Delta\tau^{B}_{NP} = \frac{1+SB}{SB}\cdot\sigma_{NP}\cdot\left(1+\frac{n}{\sqrt{3\cdot SB}}\right)$$

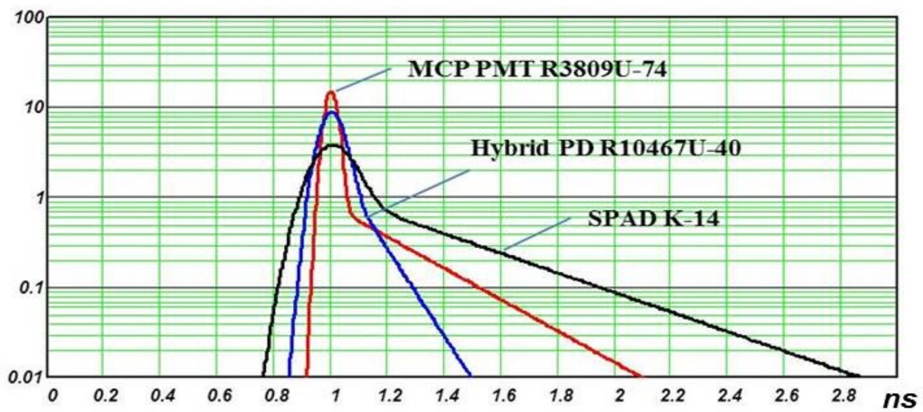
If SB<10, then data are unreliable



Analytical model of response function for various types of the single-electron photodetectors

4 parameter model of response function for single-electron photodetectors

$$p_{pd}(t,T_c,\sigma_c,\tau,\Delta) = (1-\Delta)\cdot p_{core}(t,T_c,\sigma_c) + \Delta\cdot p_{tail}(t,T_c,\sigma_c,\tau)$$



Photodetector type	T_c	σ_c	τ	Δ	σ_{pd}	Δ_{bias}
MCP PMT R3809-74	1 ns	22 ps	0.25 ns	0.2	151 ps	50 ps
Hybrid PD R10467U-40	1 ns	40 ps	0.09 ns	0.2	67 ps	18 ps
SPAD K-14	1 ns	70 ps	0.4 ns	0.42	330 ps	168 ps

1. Root-mean-square deviations of response functions significantly exceed their resolving powers;
2. To achieve the submillimeter accuracy of NP formation, it is necessary to truncate the diffusion tails;
3. Parameter Δ_{bias} gives the upper estimation of NP formation bias introduced by the photodetector.

Method
of correcting the normal point diffusion bias

Analytical assessment of the NP bias upon measurement screening in the window $\pm n \cdot \sigma$

$$\Delta\tau^{D}_{NP} = m_{trunc}(\sigma_{return}, n) - m_{trunc}(\sigma_{calibr}, n)$$

Normal point value bias in cases when the distance and calibration measurements are filtered in different windows with the sizes defined by pulse width σ_{return} and σ_{calibr}

Photodetector type	Normal point bias for n=3	Normal point bias for n=2
MCP PMT R3809-74	***27 ps***	***16 ps***
Hybrid PD R10467U-40	***13 ps***	***9 ps***
SPAD K-14	***64 ps***	***34 ps***

Normal point value bias in cases when distance and calibration measurements are filtered in the same windows with the sizes defined by the pulse width of σ_{return}

Photodetector type	Normal point bias for n=2.5		
	$\sigma_{return} = 200\ ps$	$\sigma_{return} = 100\ ps$	$\sigma_{return} = 50\ ps$
MCP PMT R3809-74	***-4.1 ps***	***-1.1 ps***	***-0.1 ps***
Hybrid PD R10467U-40	***-2.3 ps***	***-0.9 ps***	***-0.02 ps***
SPAD K-14	***3.5 ps***	***2.8 ps***	***0.7 ps***

SUMMARY

1. The new generation SLR station incorporates laser and radio measurement means and is designed to perform geodetic, time transfer and GLONASS ephemeris and time support accuracy increase tasks;

2. To achieve the submillimeter accuracy of range measurements, the single- electron receiving mode and differential method of laser ranging and normal point formation are used in the station;

3. The hybrid photodetector which has the minimal value of diffusion bias is selected as the single-electron photodetector of the SLR station.

Thank you for your attention ☺